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Trends in Drinking Water Quality for Some Wells in Qassim, Saudi Arabia, 1997-2009

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Abstract: Well water samples were collected during the period of 1997 to 2009 from seventeen wells to represent Saq aquifer, Qassim Region, Kingdom of Saudi Arabia. The water samples were analyzed to determine their quality for domestic use. The water samples were investigated with respect to Electrical Conductivity (EC), total water hardness and the concentrations of hydrogen (pH), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), fluoride (F^-) and ammonium (NH_4^+). The electrical conductivity increased slowly with time from 1.18 to 1.39 dS m^{-1}, with a mean of 1.31 dS m^{-1} for all water samples examined. The mean EC complies with the maximum permissible drinking water limits set by the local and international standards. The total hardness for the studied well water is 278.26 ppm as calcium carbonate which was classified as very hard water. Therefore, the water of wells should be softened to react with soap for domestic use. The pH in all water samples ranged from 6.77 to 7.28 with a mean of 7.02. This mean of pH complies well with standard value set for drinking water. The concentrations of the cations and anions follow, more or less, a trend similar to EC with time. The cations (Ca^{2+} and Mg^{2+}) and the anions concentrations were lower than the maximum permissible drinking water limits. The concentrations of F^- in the all of colleted samples ranged from 0.29-0.37 ppm with a mean of 0.36 ppm. The mean concentration of F^- is alarming because it is below the lower permissible limit of 0.6 ppm set by the World Health Organization. So, the water of these wells must be fluorinated before drinking use. The concentration of in all water samples ranged between 0.0 to 0.27 ppm with a mean of 0.22 ppm. In general, the concentration of is alarming because it is higher than the permissible concentration in the drinking water (0.0 ppm).

Key words: Permissible concentration, quality, water, wells

INTRODUCTION

The Kingdom of Saudi Arabia has vital water problems and needs attention toward its water use, i.e., domestic use. The problems include lack of rainfall, nonrenewable supplies, poor groundwater quality, salt water intrusion (i.e., locations close the sea shore) and contamination of aquifers. Elhadj (2008) stated that volume of water extracted from the nonrenewable aquifers in the kingdom between 1980 and 1994 was 140 Gm^3. Hubbert's theory suggests that the volume of Saudi nonrenewable water before the heavy extraction had started was likely to be around 280 Gm^3 and that the remaining volume of water around 1994 was 140 Gm^3. On this basis, such a volume would last for 10 years, if the average extraction would be 14 Gm^{3-1} annum. Al-Sulaimi *et al.* (1996) stated that the conflicting demands of the inhabitants, agriculture and industry are jeopardizing the secure provision of water supplies nationwide and also putting water quality at risk: this is because overexploitation causes salt water intrusion on the freshwater aquifers. In addition, the use of agricultural fertilizers and pesticides and the partially uncontrolled disposal of waste materials and wastewater, also expose the groundwater to considerable pollution risks. One of the main water aquifer for the groundwater in the Kingdom is Saq aquifer which extends over 1200 km in the kingdom of Saudi Arabia and northwards in Jordan (Sharaf and Hussein, 1996). The Saq formation thickness reaches more than 1000 m in the Tabuk area; in Qassim area it ranges from 350 to 750 m; southward the thickness decreases progressively and is truncated by the Khuff unconformity. Previous studies as stated by Sharaf and Hussein (1996) proved that the Saq aquifer stores significant amounts of groundwater (280 Gm^3) some 10 to 30 thousand years old. Present recharge to the Saq was estimated to be 310 Mm^3. This aquifer has been pumped heavily since the early 1970s especially in the

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areas of Tabuk, Hail, Qassim and As Sirr. Groundwater occurrences, water levels, movements, potentiality and development of the Saq aquifer have been studied by different researchers. The water quality of the Saq aquifer is generally good except for a few areas where the quality is fair, rarely poor. The total dissolved solids are generally less than 500 mg L^{-1}; higher salinities are encountered especially to the West and East of the Qassim area where irrigation return water and/or other factors are involved. Alaa-el-Din *et al.* (1994) studied the quality of 4255 well samples during 1984-1989 in the Kingdom of Saudi Arabia. They found a progressive improvement in the quality of some of the well samples during this period. However, there were a significant number of water samples showing high levels of pollutants. Nitrate levels of >45 mg L^{-1} were observed in 8% of the well samples in 1989 and 5% of them showed the presence of both elevated levels of nitrate and faecal coliforms. Chemical analysis were conducted on groundwater samples collected from 18 wells in Buraydah in 1986 by Abdelmonem *et al.* (1990). They reported that total salinity ranged between 512-1664 ppm which is high salinity for water use. Al-Awad (2004) reported that quality of groundwater in many wells in the Kingdom of Saudi Arabia has deteriorated perhaps due to saline water coning caused by high pressure drawdown. Chemical analysis for water samples collected from 72 wells of Jilh area, Northern Saudi Arabia was achieved by Saeed *et al.* (2001). Their results of the analysis indicted that 7% of the wells had permissible water quality for agriculture without any hazard, 22% of well water was moderate and 71% of the wells had unsuitable water quality. Water hardness is a traditional measure of the capacity of water to react with soap. Hard water requires a considerable amount of soap to produce lather and it also leads to scaling of hot water pipes, boilers and other household appliances. Water hardness is caused by dissolved polyvalent metallic ions. In fresh waters, the principal hardness-causing ions are calcium and magnesium; strontium, iron, barium and manganese ions (Appelo and Postma, 2005). The former researcher expressed the hardness as an equivalent concentration of calcium carbonate. The hardness can also be estimated by determining the concentrations of the individual components of hardness and expressing their sum in terms of an equivalent quantity of calcium carbonate. The degree of hardness of drinking water may be classified in terms of its calcium carbonate concentration as follows: soft, 0 to <60 mg L^{-1}; medium hard, 60 to <120 mg L^{-1}; hard, 120 to < 180 mg L^{-1} and very hard, 180 mg L^{-1} and above (Appelo and Postma, 2005). The groundwater quality can be degraded or improved by factors such as the usage period, the water discharge of a well and the formation of aquifer. Therefore, the main objective of the present study is to describe the quality of the groundwater in the Saq aquifer using seventeen wells in Qassim region during the period of 1997 to 2009.

MATERIALS AND METHODS

The present studies were achieved during the period of 2008-2009 in the Civil Engineering Department, Engineering Faculty and Qassim University. Data of water quality were obtained from Ministry of Electricity and Water, Water Directorate, Qassim, Saudi Arabia. Seventeen wells were selected in Mota area, central of Buraidah City, Qassim Region. The wells represent Saq aquifer which is a major water resource in the Saudi Arabia. This aquifer is located in the Central-North of the Saudi Arabia and made of sandstone (Al-Awad, 2004). The aquifer is 150-1500 m depth, with thickness ranged from 500 to 650 m. The well covered an area with dimensions of 2.4 ×1.8 km. Their discharges ranged from 80 to 332 m^3 sec^{-1}. The water levels in the wells ranged from 90 to 138 m. The discharges of the wells are provided by the Ministry of Electricity and Water, Water Directorate in Buraidah City, Qassim. Figure 1 shows a schematic diagram for the locations of the selected wells. These wells are numbered from 1 to 17 and specific names are provided in Table 1. The farthest distance between the wells (well 5 and 17) is 2.5 km. The water samples were collected during the period of 1997 to 2009.

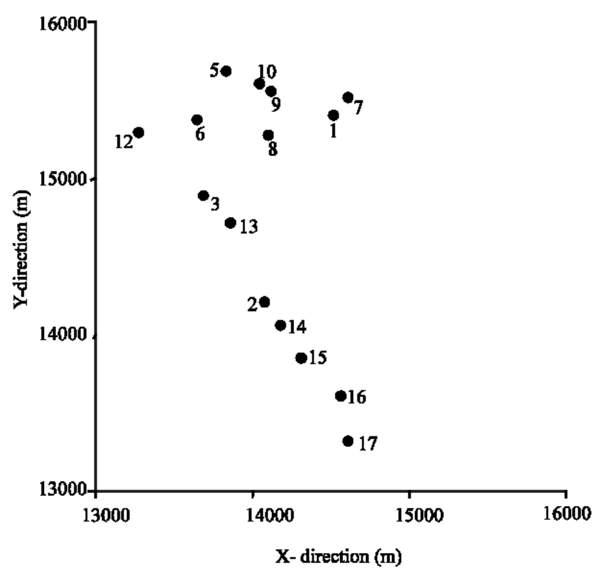

Fig. 1: Schematic diagram for the studied wells

Table 1: Discharges, water levels and well depths of the studied wells in Buraidah City, Qassim Region 2006

Well No.	Location	Discharge ($m^3\ sec^{-1}$)	Water level (m)	Well depth (m)
1	Northern Mota	332	103	650
2	Southern Mota	177	90	650
3	Southern Mota	267	114	650
4	Northern Mota	26	103	650
5	Water station	277	120	650
6	Northern Mota	310	113	650
7	Northern Mota	266	113	650
8	Northern Mota	266	117	650
9	Sources	174	117	650
10	Water station	80	104	500
11	Northern Mota	235	120	650
12	Northern Mota	108	120	500
13	Southern Mota	317	121	650
14	Southern Mota	150	106	650
15	Southern Mota	200	110	650
16	Southern Mota	200	110	650
17	Southern Mota	220	103	650

Source: Ministry of Electricity and Water, Water Directorate, 2006

Table 2: Permissible limits of different water properties for domestic uses (Al-Zarah, 2007)

Property	Permissible/ recommended upper limits
pH	6.5-8.5
EC ($dS\ m^{-1}$)	1.56
NO_3^- (ppm)	45
F^- (ppm)	1.5-2.0
Mg^{2+} (ppm)	150
Ca^{2+} (ppm)	200
Cl^- (ppm)	250
NH_4^+ (ppm)	0*
SO_4^{2} (ppm)	400*

*These values are Saudi Standards (Source: Ministry of Electricity and Water, Water Directorate, 2006)

One water sample per year was collocated from each well by Ministry of Electricity and Water, Water Directorate. But, during the years of 1999 and 2000, three water samples were collected from each well.

All of the water samples were pumped from wells continuously used. After the pump had been running for approximately 2 h the sample was collected from the rising main. The samples were analyzed through the auspices of Ministry of Electricity and Water, Water Directorate. The water samples were taken to the laboratory (ambient temperature 25°C) and analysis were carried out immediately. The analysis included nitrate, ammonium, chloride, calcium, magnesium, sulfate, fluoride, Electrical Conductivity (EC) and pH. The total water hardness was calculated from knowledge the concentrations of magnesium and calcium in forms of $CaCO_3$ (Appelo and Postma, 2005). The analysis were carried out according to the standard methods (Page *et al.*, 1982). In these analysis, pH was measured by a pH-meter. Electric Conductivity (EC) ($dS\ m^{-1}$ at 25°C) was measured by a Beckman Solute Bridge. Ca^{2+} and Mg^{2+} were determined by titration with EDTA-disodium salt solution. F^- was determined by the SPADNS [Sodium 2-(parasulfophenylazo)-1,8 dihydroxy-3,6 naphthalene disulfonate] colorimetric method. Cl^- was determined by titration using standard silver nitrate solution. SO_4^{2-} was determined turbidimetrically using turbidimete. NO_3^- was determined by the phenoldisulphonic acid method using Spectronic 2000 spectrophotometer. NH_4^+ was measured using spectrophotometer too. The obtained results are compared with the established water quality standards (Table 2) for water domestic use (Al-Zarah, 2007).

RESULTS AND DISCUSSION

The hydraulic properties of the well are given in Table 1. These properties include the discharge, the depth of wells and water level in 2006. The discharges of wells ranged between 80 (well No. 10) to 332 (well No. 1) $m^3\ sec^{-1}$. It is obvious that discharges of wells varied greatly. The respective water level varied from 90 to 131 m. The depths of wells were between 500 and 650 m.

Drinking water samples were collected from the 17 wells (throughout the Buraidah City, Qassim Region, Kingdom of Saudi Arabia) in the period 1997 through 2009. Sampling analysis included the Electrical Conductivity (EC), pH, nitrate, ammonium, chloride, sulfate, calcium, magnesium and fluoride. The data colleted represent different locations and well discharges. The results and discussion were categorized based upon the studied water quality parameters:

Electrical conductivity: The electrical conductivity reflects the total amount of soluble salt in water. Figure 2 shows the average EC in the well water during the investigation period. The EC values did show minor variations with time. The values of EC ranged between 1.19 to 1.39 $dS\ m^{-1}$ with a mean of 1.31 $dS\ m^{-1}$. The maximum value occurred during 2006 and the minimum value occurred during 1997. The variations in the EC of the wells water might be due to the continues pumping of aquifer water. The results of the present studies showed that the range of EC in the water comply well with the permissible value assigned by the Saudi standard (1.6 $dS\ m^{-1}$) (Ministry of Electricity and Water, Water Directorate, 2006; Al-Zarah, 2007). The low salinity in the water of studied area might be due to the high transmissivity of water (Italconsult, 1969; Al-Zarah, 2007). In addition, the collected water samples in the present study represent a confined aquifer. The mentioned aquifer is rarely to be polluted by high salinity of surface water recourses. So, the values of EC were low. However, pervious studies by Al-Redhaiman and Abdel Magid (2002) and Abdel Magid (1997) for water in Qassim Region

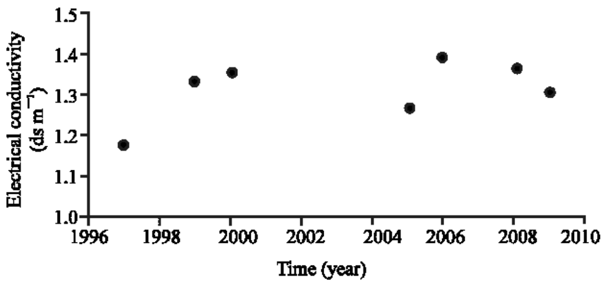

Fig. 2: Average electrical conductivity in water (1997-2009)

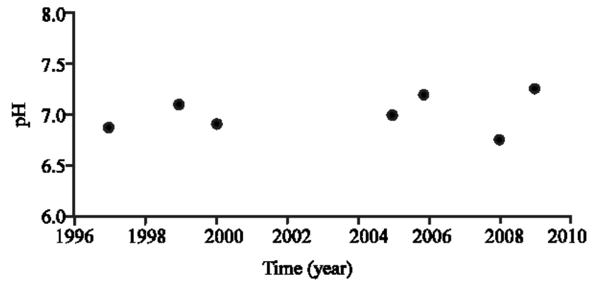

Fig. 3: Average pH in water (1997-2009)

showed higher electrical conductivity than reported in this study. They attributed the high values of EC to several factors such as over-exploitation, excessive pumping, soil weathering, run off water, agricultural drainage water and holes found in the casing of pumping wells from which high salinity water enters the wells from the upper aquifers.

pH of water: The pH value is related to the amount of hydrogen/hydroxide concentration in water. The pH values for the water samples are shown in Fig. 3. The pH in all water samples ranged from 6.77 to 7.28 with a mean of 7.02. The pH trend shows minor variations with time during the period under investigation. These values were approximately neutral which is good for drinking purposes without causing any health hazards. In addition, a neutral groundwater is a good solvent. Any significant variation in pH above or below the neutral value of 7 can affect the solubility of some salt ions present in the soil-water system or water-rock interaction. The pH values comply well with standard value set for drinking water (Al-Zarah, 2007).

Nitrate concentration: Most of the nitrogen in the groundwater is probably derived from the biosphere. The nitrogen originally fixed from the atmosphere, is mineralized by soil bacteria into ammonium, which is converted into nitrate by nitrifying bacteria under aerobic conditions (Tindall *et al.*, 1995). Figure 4 shows concentrations with time. The concentrations of ranged from 0.0 to 5.0 ppm with a mean of 1.46 ppm. The concentration of was high during 2008. In the present study, the nitrate concentration of well water is good for drinking purpose and complies well with the limit of 50 ppm as the highest tolerable nitrate content (WHO, 1984; Al-Redhaiman and Abdel Magid, 2002; Al-Zarah, 2007).

Ammonium concentration: Ammonium is a common fertilize source and is used heavily for crop production in the agriculture sector. Some of this fertilizer can be

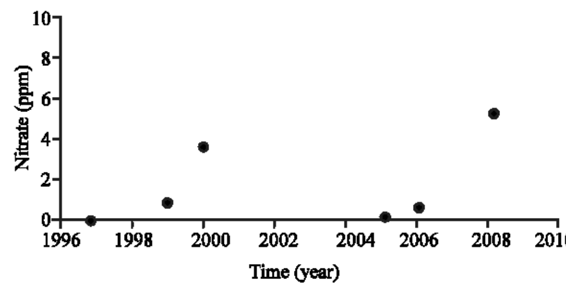

Fig. 4: Average nitrate concentration in water (1997-2009)

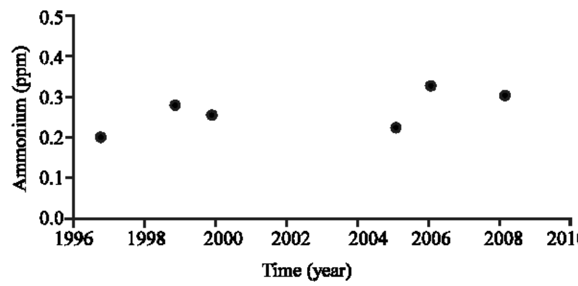

Fig. 5: Average ammonium concentration in water (1997-2009)

delivered to the groundwater sources causing pollution for this water. Figure 5 shows the ammonium concentration in the well water with time. The mean concentration for ammonium was 0.22 ppm with a range of 0.0 to 0.32 ppm. The lowest NH_4^{+1} concentration occurred in 2009 while the highest concentration accrued during 2006. These variations in concentration might be attributed to the agriculture activity in the studied area. The mean concentration of does not comply with the permissible values (0.0 ppm) as stated by Ministry of Electricity and Water, Water Directorate (2006). The drinking water should be free from the ammonium according to the Saudi standards.

Fluoride concentration: Fluoride exists fairly abundantly in earth's crust and can enter groundwater by natural processes. F^- concentration vs. time is presented in

Fig. 6. The variations in the concentration are limited during the studied period. Mean F^- concentration is 0.35 ppm with a range of 0.29 to 0.37 ppm. The mean concentration of F^- does not comply with the permissible concentration. It is very low in comparison to the permissible concentration. According to WHO (1984), F^- is an effective agent for preventing dental caries if taken at optimal amounts. In general, the fluoride concentrations in the water of all wells studied are below the recommended concentration in the drinking water. Therefore, supplemental fluoridation to the optimum level is deemed necessary to avoid dental decay in water consumers (Al-Oud, 2004). Al-Redhaiman and Abdel Magid (2002) reported similar finding for drinking water in Qassim region. They reported that 88% from the water samples contained concentration of fluoride lower than 0.6 ppm set by Saudi Arabian Standards Organization (1984). They recommended that the water of wells needs fluoridation before drinking use.

Calcium concentration: The concentration of Ca^{2+} does not exhibit large changes with time (Fig. 7). The Ca^{2+} concentration ranged from 56.89 (year of 1999) to 87.22.26 (year of 2008) ppm during the studied period. The mean concentration for that element was 72.05 ppm. Therefore, mean calcium hardness is 181.38 ppm Ca^{2+} as $CaCO_3$. The mean concentration of Ca^{2+} was lower than the permissible values in the drinking water (Al-Zarah, 2007). Therefore, water quality regarding the concentrations of Ca^{2+} is considered good for drinking by human.

Magnesium concentration: The concentration for Mg^{2+} ion shows little changes (Fig. 8) with time. The Mg^{2+} concentration ranged from 19.83 to 29.26 ppm. The mean concentration for that element was 23.52 ppm. The mean magnesium hardness is 96.88 ppm Mg^{2+} as $CaCO_3$. The mean concentration of Mg^{2+} was lower than the permissible values in the drinking water. Magnesium has a positive effect on reducing the risk of diseases for human. Rylander *et al.* (1991) reported that a significant inverse relationship between water hardness and mortality from cardiovascular diseases for both sexes. They also reported that mortality caused by ischemic heart diseases was inversely related to the magnesium content.

Total water hardness: The water hardness resulted from the calcium and magnesium are 181.38 and 96.88 ppm as calcium carbonate, respectively. The total water hardness for the studied well water is 278.26 ppm as calcium carbonate. According to the total hardness, the water is very hard as the scale set by Appelo and Postma (2005). Therefore, the water of wells should be softened to react with soap for domestic use.

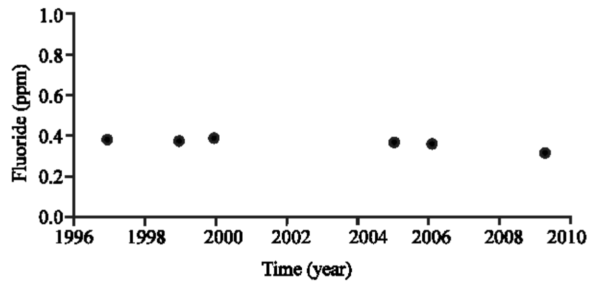

Fig. 6: Average fluoride concentration in water (1997-2009)

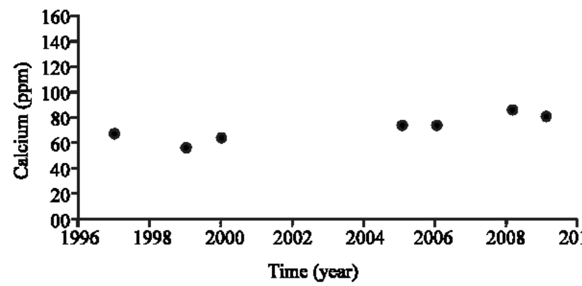

Fig. 7: Average calcium concentration in water (1997-2009)

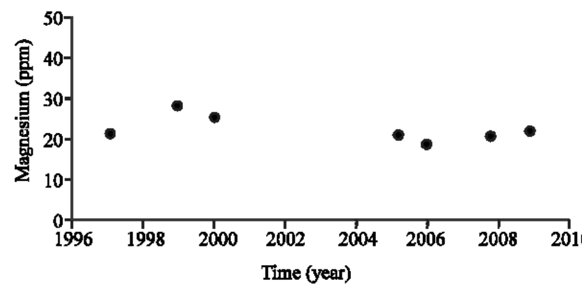

Fig. 8: Average magnesium concentration in water (1997-2009)

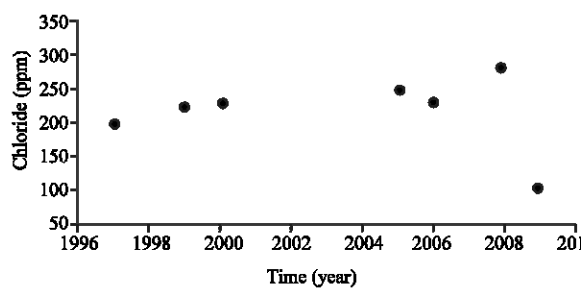

Fig. 9: Average chloride concentration in water (1997-2009)

Chloride concentration: The data of chloride for the well water are presented in Fig. 9. Cl^- concentration ranged from 101.88 to 282.77 ppm and the mean concentration of

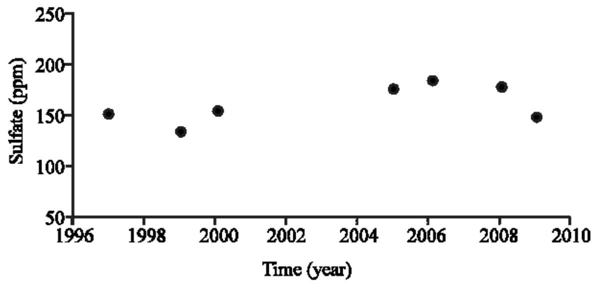

Fig. 10: Average sulfate concentration in water (1997-2009)

Cl^- was 217.89 ppm. The chloride concentration was the lowest during year of 2009, while there were minor changes in the concentration of chloride between years of 1997 till 2008. The mean concentration of Cl^- is below the permissible concentration in the drinking water (250 ppm) (Al-Zarah, 2007). However, the highest Cl^- concentration, which occurred during 2008, was greater than the permissible concentration. This concentration is alarming to minimize the concentration of Cl^- by water treatment. The high concentration of chloride is mainly due to solubility of some minerals presented in formation of aquifer.

Sulfate concentration: Figure 10 shows the concentration of SO_4^{2-} with time during the investigated period. The concentrations of sulfate show minor variations during the studied period. Its concentrations ranged from 137.82 to 188.46 ppm. The mean concentration for sulfate was 165.06 ppm. In general, the concentrations of complies well with the permissible concentration in the drinking water (Ministry of Electricity and Water, Water Directorate, 2006).

CONCLUSIONS

Water samples were collected during the period 1997 to 2009 continuously from seventeen wells. The wells are located in Mota area, Qassim region, Saudi Arabia and represent the Saq aquifer. The water samples were obtained once or three times a year during 1997 to 2009 after two hours of pumping. The samples were analyzed chemically for several parameters. These parameters are EC, pH, F^-, Ca^{2+}, Mg^{2+}, Cl^-, NH_4^+ and SO_4^{2-}. These parameters are essential for defining the availability of water for domestic use. In addition, water hardness was calculated from knowledge the concentrations of Ca^{2+} and Mg^{2+}. Some hydraulic properties of the well are presented too.

Based on the results of the present investigation, the following conclusions may be drawn:

- The depths of the well ranged from 500 to 650 m
- The discharges of wells varied from 80-310 m^3 sec^{-1}
- Comprehensive analysis of the water samples revealed that the concentrations of the studied parameters did not change considerably during the studied period
- Based upon the permissible concentration in the drinking water, the values of EC, pH, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-} are lower than the permissible limits Saudi Arabian Standards Organization and other guidelines. So, the water of these wells are good for human use regarding these elements.
- Most of the water samples contained percentage of NH_4^+. Based upon the permissible limit set by the Saudi Arabia for drinking water, the water should be free of NH_4^+
- The total hardness for the studied well water is 278.26 ppm as calcium carbonate. So, the water should be softened for domestic uses
- NO_3^- concentrations of the water samples examined pose no health hazards to the public health since they fall well below the maximum permissible limit of the respective standards used in this study.
- The concentrations of F^- in drinking water are alarming since 100% of the water samples studied have F^- concentrations below 0.6 ppm (the lower permissible limit of F^- suggested by the Saudi Arabian Standards Organization). Therefore, fluoridation of the water of Qassim region must be performed before use it for drinking
- Continuous assessment of groundwater quality on routine basis is imperative and a better management is warranted to reduce the deterioration of aquifer water quality

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